

# APPARATUS FOR, AND METHOD OF, VARYING THE RATE OF FLOW OF FLUID ALONG A PATHWAY

## 5 Technical Field

This invention relates to an apparatus for and method of varying the rate of flow of a fluid along a pathway. More particularly, but not exclusively, the invention varies the rate of flow of fluid along a pathway in a wet chemistry analysis system.

## 10 Background Art

A common feature of all "wet chemistry" analysis or assay systems is that analyte, together with one or more reagents, usually passes through a series of processes or procedures. These include: mixing, reacting, incubating, filtering, decanting, metering and dividing. In short, some form of fluid handling is a common and important feature of most assay

15 systems.

International Patent Application WO-A1-9419484 (Biocircuits Corporation) describes a disposable device for use in diagnostic assays and comprises a number of chambers and interconnecting pathways. Capillary valves are used to enhance control over fluid flow in

20 the device. One type of capillary valve comprises a fluid flow capillary channel and a control capillary channel which intersect each other at right angles. The intersection disrupts fluid flow in the flow capillary channel when the control capillary is empty, but does not impede flow through the flow capillary channel when it is full. Thus, fluid flow through the device can be controlled by either filling or emptying the control capillary with

25 liquid.

A similar disposable device is described in International Patent Application WO-A1-9727324 (David Sarnoff Research Center). This device uses valves and pumps for controlling the flow of fluid. The valves used may be of the plunger type such that the

30 valve has a piston and plunger rod. The diameter of the plunger rods is typically of the order of 60  $\mu\text{m}$  and the piston diameter is typically of the order of 200  $\mu\text{m}$ .

In US Patent No. 5,267,585 (BOC Health Care), a flow control valve is disclosed. A deformable elastomeric element is positioned at least partially within the flow path of a

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fluid passing between an inlet and an outlet. By deforming the elastomeric element, the cross-section of the flow path of the fluid is changed, thereby controlling the flow of fluid through the flow control valve.

- 5 A temperature operated gas valve is described in US Patent No. 4,949,742 (Spectra-Physics). The valve includes a conduit positioned between high and low pressure gas regions. Within the conduit is a restriction, and this restriction is closed by a meltable solid material. When the valve is to be opened, heat is applied to the meltable solid material, causing some of the material to flow and allow the passage of gas from the higher pressure
- 10 region to the lower pressure region. When the pressure between the two regions has substantially equalized, surface tension associated with the restriction in the conduit pulls the liquified material back into place to close and reseal the valve.

- A capillary transport device having an internal capillary transport passage is disclosed in
- 15 US Patent No. 4,549,952 (Eastman Kodak). To control the liquid flow rate in the passage, a water-swellable composition (such as gelatin or starch) is used.

- International Patent Application WO-A1-9822625 (University of Michigan/Becton Dickinson) discloses methods and compositions for isothermal amplification of nucleic
- 20 acids in a micro-fabricated device. The device includes fluid channels connected to an isothermally regulated reaction chamber. Fluid flow in the channels may be regulated by the use of meltable materials placed in or alongside the channels.

- In US Patent No. 5,278,079 (Enzymatics Inc.) a diagnostic device having capillary tubes is
- 25 described. The capillary tubes contain a volume of water-expandable polymer which forms

a seal in the tubes when it is in contact with an aqueous medium. However, once sealed, the capillary tubes cannot be easily reopened.

In conventional analysis techniques, fluid handling relies on precisely engineered fluid controllers such as valves, taps and fluid delivery systems. These fluid controllers are expensive and difficult to manufacture. They are therefore not appropriate for inclusion in disposable units due to their number and cost.

An aim of the present invention is to overcome the aforementioned problems by providing a means for varying the flow of fluid along a pathway.

#### Disclosure of Invention

According to a first embodiment of the invention there is provided a method of varying the rate of fluid flow along a pathway comprising the steps of: providing at least one recess located substantially adjacent the pathway; locating a plug of deformable material in the pathway so that the material substantially restricts the flow of fluid in the pathway; and changing the state of the deformable material so that at least a portion of the material passes into the at least one recess thereby permitting flow of the fluid along the pathway.

According to a second embodiment of the invention there is provided method of varying the rate of fluid flow along a pathway comprising the steps of: providing at least one recess located substantially adjacent the pathway; locating a volume of deformable material in the at least one recess; and changing the state of the deformable material so that at least a portion of the material passes into the pathway thereby substantially restricting flow of the fluid along the pathway.

According to a third embodiment of the invention there is provided a method of varying the rate of fluid flow along a pathway comprising the steps of: providing a pathway; locating a volume of deformable material in the pathway so that it substantially restricts the flow of fluid along the pathway; and changing the state of the deformable material so that at least a portion of the material passes along a predetermined path thereby permitting flow of the fluid along the pathway.

According to a fourth embodiment of the invention there is provided a method of varying the rate of fluid flow along a pathway comprising the steps of: providing a pathway; locating a volume of deformable material in the pathway so that it substantially permits the flow of fluid along the pathway; and changing the state of the deformable material so that at least a portion of the material passes along a predetermined path thereby substantially restricting flow of the fluid along the pathway.

Preferably the predetermined path is defined by one or more regions that repels or attracts the deformable material. A region having such a property is hereinafter referred to as being hydrophobic.

The state of the deformable material may be changed by applying to the deformable material (i) heat, (ii) pressure, (iii) uv radiation, (iv) light, (v) ultrasonic energy or a combination of any of (i) to (v).

According to a further embodiment of the invention there is provided an apparatus for varying the rate of fluid flow along a pathway, the apparatus including at least one pathway and a volume of deformable material disposed within the pathway whereby, in use, a change of state of the deformable material causes a change of the rate of fluid flow along the pathway.

According to another embodiment of the invention there is provided an apparatus for varying the rate of fluid flow along a pathway, the apparatus including at least one pathway and a volume of deformable material disposed adjacent the pathway whereby, in use, a change of state of the deformable material causes a change of the rate of fluid flow along the pathway.

The apparatus may also include at least one chamber in fluid connection with one or more pathways. A volume of deformable material may be disposed within the at least one chamber.

At least one recess capable of receiving deformable material is preferably located substantially adjacent the at least one pathway. The at least one recess may have an opening which acts as a vent in order to permit the flow of gas therethrough.

- 5 The apparatus may also include at least one hydrophobic region. Thus the flow of material is guided along a predetermined path and discouraged from contacting other regions of the pathway, chamber, or device.

10 The apparatus may include means for the supply and/or removal of heat from the apparatus in order to increase or decrease the rate of change of state of the deformable material. When heat (or other form of energy) is applied to a region of the apparatus containing the deformable material, the material may change its position, size, state or function. This causes a rate of change in the fluid flow in the pathway. Thus a pathway which is initially obstructed becomes unobstructed, and vice versa.

- 15 Heater elements may be printed onto the apparatus or a heating tool may be used to apply heat to local areas of the apparatus. Alternatively, heat may be applied to or removed from larger regions of the apparatus, or to a device which includes the apparatus. For example, by dipping into a water bath, heating with an external heater, or by a Peltier.

20 The apparatus may also include means for the supply of pressure, uv radiation, light, ultrasonic energy, or other suitable means for changing the state of the deformable material.

- 25 The deformable material may be a thermally activated material. Preferably the thermally activated material is wax, contains or is a polymer such as polypropylene polystyrene, a wax/polymer mix, a metal such as Indium, or any other suitable low melting point material that changes its state on application of heat, and on cooling. The terms thermally activated material and wax are hereinafter used interchangeably.

30 In summary, fluid flow along a pathway of the apparatus is varied by way of valves, or clamps, which are preferably formed from a deformable material. The valves and clamps

may be opened and/or closed upon the application of heat, pressure, or other suitable means. The valves and clamps may also be known as gates. Hereinafter, a gate that opens a pathway to the flow of fluid on application of heat is known as a heat openable gate. A gate that closes a pathway to the flow of fluid on application of heat is known as a heat closable gate.

One example of a heat openable gate has thermally activated material situated in the pathway so as to enable the material in its melted state to flow into at least one recess substantially adjacent the pathway. Air (or other gas) is displaced from the recess by the material and exits through a vent. A type of heat closable gate has thermally activated material situated in at least one recess substantially adjacent the pathway. As the material in its melted state flows from the recess into the pathway, it is replaced by air (or other gas) via the vent.

Alternatively, (or in addition to the material being situated in at least one recess), the material may be situated in the fluid pathway such that the pathway is either substantially or partially obstructed. If the thermally activated material is substantially obstructing the pathway, then the pathway may be opened to the flow of fluid by applying heat to the material. This is a form of heat openable gate. However, if the material is situated so as not to, or only partially, obstruct the flow of fluid, on application of heat the material melts and flows so as substantially obstruct the pathway. This is a form of heat closable gate.

In a further alternative embodiment, thermally activated material may be arranged to contact at least two points on inner surfaces of the apparatus, forming a clamp. Clamps may be situated in chambers. Upon application of heat to a clamp, the clamp melts, and surfaces of the chambers are separated. Thus a pressure differential is provided to drive fluid along pathways and into, or from, chambers.

Preferably at least one surface contained within the apparatus is resiliently deformable. This is advantageous because it means that if the surfaces are constructed from sufficiently pliable materials, pressure may be applied to a surface, and the surfaces will return to their original state.

Pathways may contain a volume of material so that upon application of pressure, a rate of change of fluid flow in the pathway occurs. The material may be thermally activated. Thus for a heat closable pathway, a tool may be used to seal the pathway by connecting the upper and lower surfaces with the thermally activated material. Thermally activated material may not be required if the upper and lower surfaces of the pathway may be directly connected to one another. For a heat openable pathway, a tool may make a channel in the wax contained in the pathway. When this occurs the resiliently deformable material of the pathway returns to a previous state. Pathways opened in this way may be resealed by heating and subsequent cooling of the wax.

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Preferably the volumes of deformable material may be accessed independently and sequentially to precisely control the path of fluid flow in the apparatus.

Valves and clamps may be single use structures, or may be reusable.

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The invention may be incorporated into a chemical assay device. The assay device preferably has at least one chamber in fluid connection with at least one pathway, the pathway being adapted to allow fluid to flow to or from said chamber, characterised in that there is provided a volume of deformable material in the pathway whereby, in use, a change of state of the deformable material causes a change of the rate of fluid flow along the pathway.

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The deformable material may be situated in the pathway such that the pathway is substantially obstructed or, alternatively, the material may be situated in the pathway such that the pathway is only partially obstructed.

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At least one recess may be located substantially adjacent the pathway, the recess being capable of receiving the deformable material.

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According to another embodiment of the invention, the assay device preferably has at least one chamber in fluid connection with at least one pathway, the pathway being adapted to allow fluid to flow to or from said chamber, characterised in that there is provided a volume of deformable material situated in a recess, the recess being located substantially

adjacent the pathway whereby, in use, a change of the deformable material causes a change of the rate of fluid flow along the pathway.

An opening may be provided in the recess which acts as a vent.

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The chamber may comprise a deformable envelope and at least two points on the envelope may be connected by way of a volume of deformable material.

10 A region of the device may have at least one hydrophobic portion so that the flow of the deformable material is guided along a predetermined path.

Preferably the deformable material is thermally deformable. The material may, however, be mechanically deformable.

15 The device may include heating means for melting the thermally deformable material. The device may also include means for removing heat such as, for example, a heat sink. Heat may selectively be applied and/or removed from individual wax gates and/or clamps.

20 Preferably at least one surface defined by or in the device is resiliently deformable so that the wax gates and/or clamps may be mechanically deformed.

The device may have at least one component from the set of: an inlet port, a reaction chamber, a waste depot, a filter chamber, an infinity capture and processing chamber, a wash solution/reagent reservoir, an array of metered readout cells, and a breather tube.

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The assay device is usually rectangular, but other shapes are equally viable, such as discs or hexagons. Depths of fluid pathways and chambers may be sufficiently narrow to allow filling by capillary action (say 0.02 to 0.2 mm). Pathways may be wider (of the order of a millimeter) where the fluid flow is to be propelled by gravity, a pressure impulse, centrifugal force, or an inertial force. The aforementioned dimensions are consistent with processing fluid samples in the range of approximately 30 to 50 microlitres, and are given by way of example only.

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According to a further embodiment of the invention there is provided a method of manufacturing an assay device, the method including the steps of: a) defining at least one fluid pathway on a substrate; b) defining at least one reaction chamber on a substrate; c) forming at least one component composed of a deformable material in the device; and d) bonding together at least two substrates to form the device.

The body of the assay device is preferably formed from a polymer or from a combination of materials including glass, ceramics, or metal. Construction may involve injection moulded components, and/or the joining together of a number of laminae. Pathways and chambers in the assay device may be formed in a plane defined between upper and lower planar sheets. Pathways and chambers may be formed by printing, etching, ablation, cutting of the substrate, moulding of a substrate, or a combination of these. More complex structures may be realised by building up laminae and providing vias for the flow of fluids between adjacent levels.

Bonding of upper and lower portions of the device is critical for its operation. Bonding can be achieved by means of screen printed adhesives containing for example spacer balls, by cut adhesive gasket materials, by heating sealing, by uv curing, by mechanical fixing, by ultrasonic bonding, or by using a porous-gasket technique, for example as described in US-A-4,865,716.

The assay device may include one or more of the aforementioned gates, valves or clamps. Preferably each individual gate, valve and/or clamp may be accessed independently one from another.

Wax gates and clamps may also be printed using molten wax or wax dissolved in a solvent, by injection of molten wax into the device using feeder tubes, by etching of the device, or by placing individual wax elements within the apparatus using pick and place equipment.

Provision may be made for fluid overflow lines, for collection of waste, and for opening and sealing of the device at stages from start of use until disposal.

Brief Description of Figures

Embodiments of the invention will now be described by way of examples, and with reference to the accompanying Figures in which:-

- 5 Figure 1 is a schematic plan view of a chemical assay device incorporating the invention;

Figure 2a is a plan view of a pathway having an initially open wax gate, where wax is situated in recesses adjacent the pathway;

- 10 Figure 2b shows a plan view of the pathway of Figure 2a, where the wax gate has been closed upon the application of heat to the gate;

Figure 3a shows a plan view of a pathway having an initially open wax gate, where a volume of wax is situated in the pathway;

- 15 Figure 3b shows a plan view of the pathway of Figure 3a, where the wax gate has been closed upon the application of heat to the gate;

Figure 4a shows a plan view a pathway having an initially open wax gate, where a volume of wax is situated in the pathway;

- 20 Figure 4b shows a cross-section of the pathway of Figure 4a;  
Figure 4c shows a cross-section of the pathway of Figure 4a, the pathway having been closed on application of heat and pressure;

Figure 5a shows a plan view of a pathway having an initially closed wax gate, where wax is situated in the pathway, and recesses adjacent the pathway;

- 25 Figure 5b shows a plan view of the pathway of Figure 5a, where the wax gate has been opened upon the application of heat to the gate, wax having flowed into the recesses adjacent the pathway;

- 30 Figure 6a shows a plan view of a pathway having an initially closed wax gate, where a volume of wax is situated in the pathway;

Figure 6b shows a plan view of the pathway of Figure 6a, where the wax gate has been opened upon the application of heat to the gate;

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Figure 7a shows a cross-section of a pathway having a wax gate which has been closed, and a heating tool;

Figure 7b shows a cross-section of the pathway of Figure 7a, where the pathway has been reopened to the flow of fluid upon application of heat and pressure;

5 Figure 7c shows a plan view of Figure 7b;

Figure 8a shows a plan view of a wax clamp used in a chamber, in which the clamp may be initially closed or open;

Figure 8b shows a cross-section of an deflated chamber having a wax clamp;

10 Figure 8c shows a cross-section of an inflated chamber having a wax clamp;

Figure 9a shows a plan view of a chamber containing a gas generating mixture in fluid connection with a pathway having an initially closed wax gate;

15 Figure 9b shows a plan view of the chamber of Figure 9a having an opened wax gate where fluid has flowed into the chamber (under capillary action or external pressure), and is in contact with the gas producing material contained within the chamber;

Figure 9c shows a plan view of the chamber of Figure 9a where fluid has been driven out of the chamber by a gas; and

Figure 9d shows a cross-section of the chamber and connecting pathway of Figure 9a.

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#### Detailed Description of Preferred Embodiments

The embodiments of the invention shown in Figures 2 to 9 may be incorporated into the chemical assay device of Figure 1, or they may be included in other types of assay (or other) devices.

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Referring to Figure 1, there is shown a chemical assay device 10 for analysis of blood, or other biological fluid. End products of a reaction or assay may be detected using optical methods. For example, a colour change may be detected by a photo-diode, or a fibre-optic system, or visually. The device has an area typically about 50 cm<sup>2</sup> and is 3 to 10 millimetres thick. The device 10 may be significantly larger or smaller depending on the complexity of the processes to be carried out and the volumes of fluids to be processed. In this particular embodiment, the assay device 10 is configured to carry out an

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immunological assay and this will be described so as to illustrate a method of operation of the invention.

Assay device 10 comprises a generally square, substantially planar substrate in which a number of chambers are interconnected by pathways. Fluid control in the device 10 is by way of wax gates and clamps, which are shown in Figure 1 in their initial (open or closed) states.

The device 10 includes an inlet port 12 in fluid connection with a reaction (e.g., lysing) chamber 14 via a pathway 12a. Chamber 14 leads to waste depot 16 and filter chamber 18 via separate fluid channels 14a and 14b respectively. Filter chamber 18 is in fluid connection with chambers 22 and 24 via respective fluid channels 18a and 18b, and with processing chamber 20. Chamber 22 is initially filled with a wash solution, and chamber 24 is filled with an eluent which is used to displace material from processing chamber 20.

Processing chamber 20 is connected to waste depot 16 via a channel 20a. Channel 20a leads to an array of metered read-out cells 26, 28, 30 and 32. Air from read-out cells 26 to 32 exits into channel 16a. A channel 16b is provided and links channels 20a and 16a. The operation of one of the metered readout cells will now be explained with reference to readout cell 26 of Figure 1.

A region of the analysis area of device 10 comprises a large-bore inlet port 26a leading to a fixed-volume cell 26, which in turn is connected to a narrow-bore outlet tube 26b. Tube 26b leads to pathway 16a, and ultimately to waste depot 16. The structure comprising parts 26a, 26 and 26b has a fluid impedance which is dependent on the amount of fluid therein. Fluid can flow freely into the cell until the narrow-bore section is reached, at which stage the force needed to continue driving the fluid into the cell is greatly increased. At this point the fluid, which flows most readily along the path of least resistance, diverts to the conduit leading to the next cell (28 in this case), and so on. Thus each of the cells 26, 28, 30, 32 is filled in turn, and the volume of fluid entering each cell can be controlled.

Chamber 20 is also connected to chamber 38 via a fluid pathway 20b, and chamber 38 leads to chamber 40. Chambers 38 and 40 both contain wax clamps. Both chambers 38 and 40 are initially deflated.

- 5 Waste depot 16 connects to breather tube 13 via pathway 16c, and reservoir 22 leads to breather tube 11 via pathway 22a. Breather tubes 11 and 13 ensure that fluid moves freely within the device. Also tubes 11 and 13, when connected to non-critical regions, ensure that any excess fluid does not interfere with any on-going analysis.
- 10 Reservoir 24 is connected to chamber 42 via pathway 24a. Chamber 42 is pre-filled with a dry mixture which, when in contact with a liquid, produces a gas. This is shown diagrammatically in Figure 9.

- 15 Wax gates are situated in fluid pathways in order to control flow of fluid between the chambers. In Figure 1, gates are shown in their initial states. For example, fluid flow is initially obstructed at gate 34, whereas initially fluid is allowed to flow freely through gate 36.

- Referring again to Figure 1, a typical sequence of events for an immunological assay is now described. A blood sample (not shown) is injected into the assay device via inlet port 12. Blood fills reaction chamber 14 by capillary action and/or hydrostatic pressure, and excess blood enters the waste depot 16 via pathway 14a. The blood remains in chamber 14 for as long as is required for cell lysing to occur with a reagent. The reagent is introduced into this chamber in a predetermined dose during the manufacture of the device. Heat is then applied to gates 44, 46 and clamp 48 in order to close gate 44, open gate 46, and release clamp 48 thereby actuating partial vacuum chamber 38.
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- The lysed blood is then urged through filter chamber 18 by way of a partial vacuum, and serum fills processing chamber 20. An antigen in the blood serum then bonds to an antibody which has been tagged onto, for example, glass or ceramic beads (not shown). The beads are pre-dosed and introduced in chamber 20 at the manufacturing stage.
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The serum is then washed from the glass beads in chamber 20 by activating heaters at gates 50, 52 and 54, and clamp 56. A partial vacuum in chamber 40 draws wash fluid from chamber 22 through chamber 20 leaving the antigen bound to the particles in chamber 20. Waste wash solution and serum enter chambers 38 and 40.

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The next step is elution. Activating heaters placed at gates 57, 58, 60, 36, 34 and 62 allow the fluid in the reagent reservoir 24 to wet a gas producing powder. Fluid is then driven by the gas through chamber 20 towards analysis cells 26, 28, 30 and 32. As eluent from reservoir 24 passes through chamber 20, antigen is released from the beads and carried in the eluent to the analysis cells. These cells contain reagents such as enzyme systems which react with the antigen, causing either a colour change in the solution, or a change in fluorescence. Any recognised method of optical analysis can then be used for detection and measurement of end products of the reactions. Once cells 26, 28, 30 and 32 are filled, resistance to fluid flow increases in the narrow exit channels 26b, 28b, 30b, and 32b. Excess fluid is then expelled to waste depot 16 through channel 16b.

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Finally, activating heaters at gates 66, 68 and 70 seal the fluids within the device for hygienic disposal.

Further embodiments of the invention are described now with reference to Figures 2 to 9 inclusive.

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Figure 2 shows a plan view of a section of a pathway having a wax gate 73 that closes the pathway to the flow of fluid on application of heat. A volume of wax is contained in recess 72. Pathway 75 has a region of hydrophobicity 76 in order to guide the flow of wax. Upon application of heat to gate 73, the wax melts and flows (guided by the hydrophobic region) into the fluid pathway to obstruct the flow of fluid therein. Air enters through inlet 74 and replaces the wax in recess 72. Thus air prevents flowback of the molten wax. As the wax cools, fluid flow along the pathway becomes obstructed.

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In Figure 3 a plan view of a section of pathway having a wax gate 77 is shown. Gate 77 closes pathway 75 to the flow of fluid on application of heat to the gate. A volume of wax 78 is situated in the path of the fluid, only partially obstructing the fluid flow. Upon

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application of heat to the gate, the wax melts and flows to block the pathway guided by the area of hydrophobicity 76. As the wax cools fluid flow along the pathway becomes obstructed.

- 5 Figure 4 shows another form of heat closable pathway. A volume of wax 78 is situated in pathway 75, only partially obstructing the flow of fluid. In order to block the channel, a moveable heat sealing tool 80 is used to apply both pressure and heat, completely sealing the channel. This form of gate requires that at least one sheet forming the pathway is formed from deformable material. If the deformable material can be directly sealed to the  
10 second sheet (by heat, pressure or otherwise), then wax is not required.

Figures 5, 6 and 7 all represent forms of heat openable pathways, that is, wax gates that are initially closed to fluid flow in the pathway.

- 15 Figure 5 shows a plan view of a section of a pathway 75 having a gate 79 that opens the pathway to the flow of fluid on application of heat to the gate. A volume of wax is situated in the pathway between two recesses 72. The recess has a region of hydrophobicity 76 in order to guide the flow of wax. Upon application of heat to the gate, the wax melts and flows into the recess. Air exhausts via inlet 74 and is replaced by the wax in the recess,  
20 preventing flowback of the molten wax. As the wax cools the fluid pathway opens.

- Referring to Figure 6, there is shown a plan view of a section of pathway 75 having another form of wax gate 81. The gate opens the pathway to the flow of fluid on application of heat to the gate. A volume of wax 78 is situated in the path of the fluid  
25 preventing fluid flow. Upon application of heat to this wax gate, the wax melts and flows in the pathway guided by the area of hydrophobicity 76. As the wax cools, the fluid pathway permits fluid to flow along the pathway.

- Figure 7 shows another heat openable gate situated in pathway 75. A volume of wax 78 is  
30 situated in the pathway, obstructing the flow of fluid. In order to open the pathway to allow the flow of fluid, a moveable heat sealing tool 80 is used to apply both pressure and heat to the pathway. The shape of this heat sealable tool allows the wax to be deformed, forming a channel in the wax. This type of gate requires that at least one sheet forming the pathway is

deformable and resilient, so that the sheet may return to its original state and leave the pathway open.

In addition to the aforementioned wax valves, components to actuate fluid flow may be required. Capillary action may be used to provide some fluid movement, and this can be extended by opening further fillable or absorbent areas or by opening valves of the types previously described. However, greater flexibility is achieved by employing structures capable of generating pressure differentials, and these are shown in Figures 8 and 9.

Figure 8 shows a chamber 38 containing a wax clamp 78. Changing the shape and volume of chamber 38 provides a pressure differential to drive (or suck) fluid in the connected pathways and chambers. Two sheets of synthetic plastics material 37a and 37b are fixed together using a volume of wax 78 in order to produce a deflated chamber 38. Upon application of heat, wax clamp 78 melts. This allows the surfaces of chamber 38 to separate thereby inflating the chamber. This results in a pressure change and fluid is sucked through interconnecting pathways. Chamber 38 may be returned to its deflated state by the application of an external pressure (shown in the direction of arrow A) and by heating the wax. As the wax cools, the deformable surfaces are fixed together.

Figure 9 shows a further means of generating pressure in order to drive the flow of fluid. Figure 9 shows a chamber 88 connected to a pathway having a closed wax gate 86. The chamber contains a dry gas generating mixture 82, for example sodium bicarbonate with tartaric acid. On applying heat to the wax gate 86, the wax flows to unblock the pathway 85. A solution 84 flows into the chamber 88, wetting the gas generating mixture and causing the generation of a gas. The gas increases the pressure inside the chamber, ejecting the liquid that has flowed into the chamber and propelling it along one or more interconnecting pathways. In addition to the gas generating mixture, an inert absorbent material may be included in the chamber, or the chamber may be filled with capillary matting which acts as a wick.

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The invention has been described by way of a number of embodiments, and it will be appreciated that variation may be made to these embodiments without departing from the scope of the invention.